LBNE Target Hall Instrumentation

Bob Zwaska

January 27, 2010

Target Hall Instrumentation

- Additional instrumentation in and near target hall to support beam operation
  - Commissioning
  - Beam-based Alignment
  - Beam Permit
  - Long-term Monitoring
- Interfaces with other instrumentation systems
  - Primary beam
  - Systems (RAW, air, temps)
  - Neutrino beam monitors
- Varying needs of reliability
  - Every pulse for beam permit
  - Monthly or yearly for alignment/commissioning
- Software is needed to bring everything together

This is an initial brainstorm – please provide input

Approach

- We have a good base of experience with NuMI
  - We know its strengths and weaknesses
- Have additional constraints in LBNE
  - More powerful beam
  - Possibly higher rate of target change-outs
  - Would like greater reliability
- Want some additional functionality
  - Target decay
  - Better software tools

Quick list of NuMI Tools/Instrumentation

- **Shape of target and baffle**
- **Cross-hairs on horns, and horn neck**

} Features used

- **Baffle thermocouples**
- **Budal Monitor**
- **Horn BLMs**
- **Hadron Monitor**
- **Muon Monitors**

} "Target Hall" Instrumentation

- **BPMs**
- **Profile Monitors**
- **Toroids**
- **MINOS Near Detector**

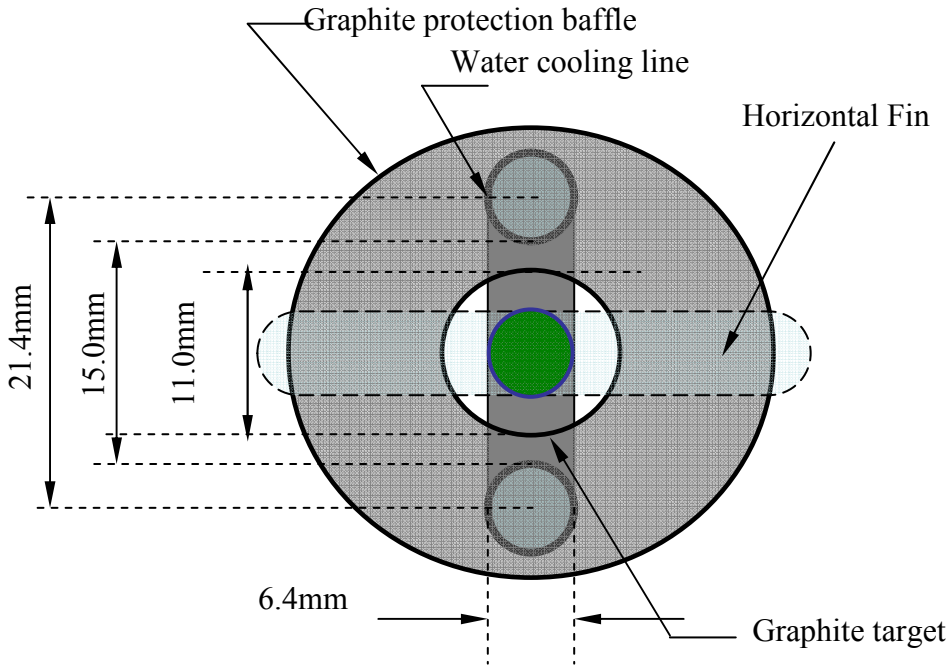
} External Instrumentation

NuMI Target/Baffle Shape

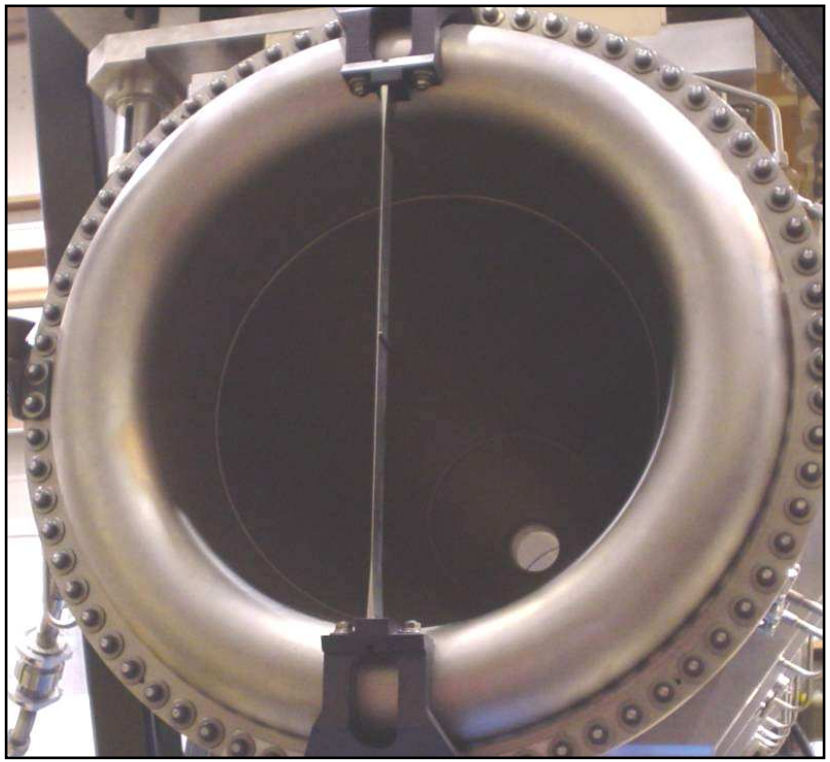
- Target and baffle stack produced high-contrast features
  - Gap between baffle and target
  - Horizontal fin
- Beam was scanned across features
- Response measured in instrumentation

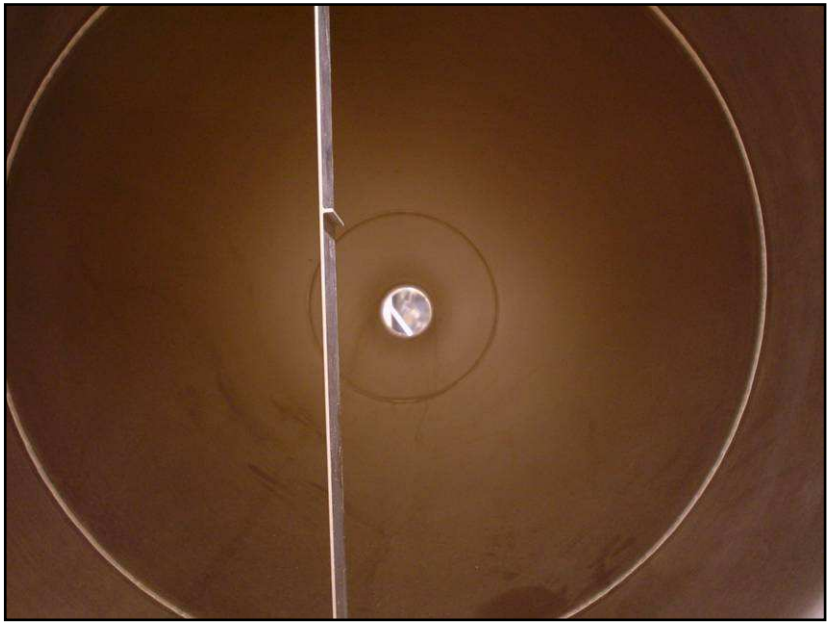
- LBNE target may not have these features
  - We need to get something similar

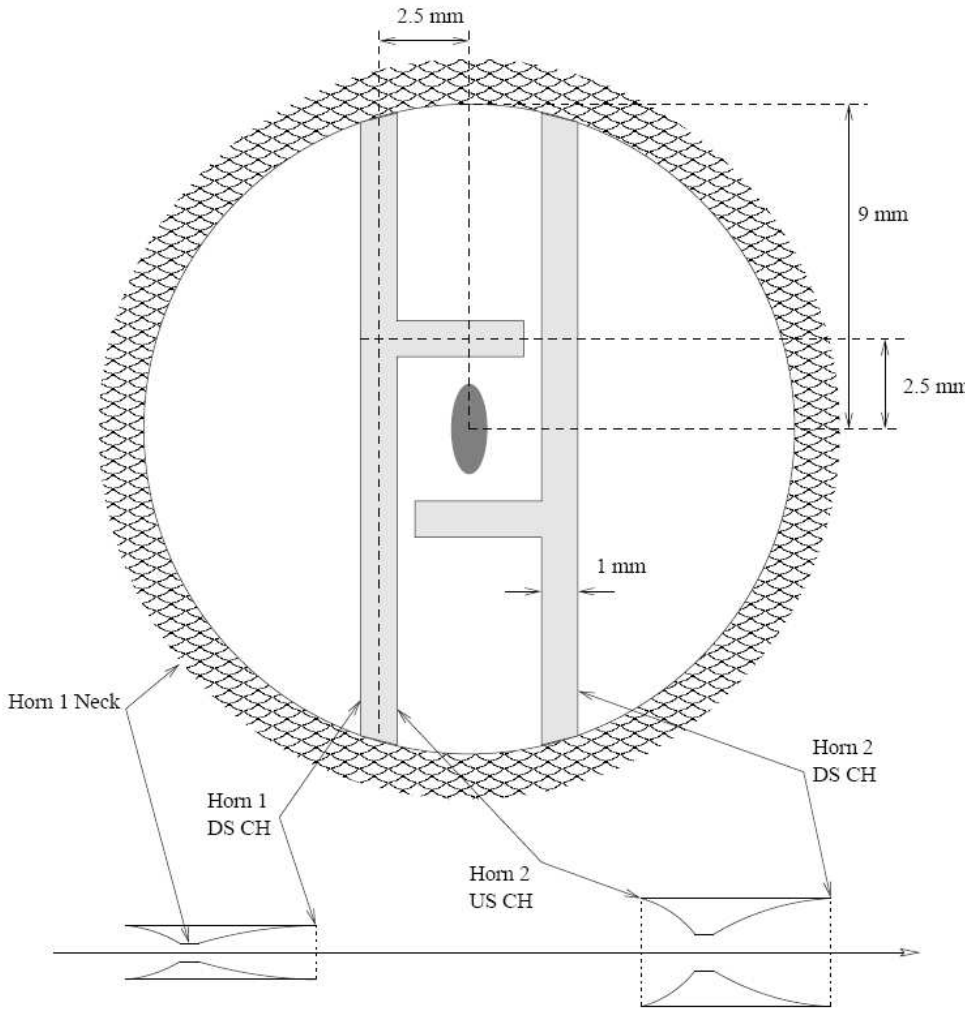
- Baffle thermocouples: calibrated so that baffle temperature was a measure of beam scraping, and in which direction



NuMI Cross-hairs



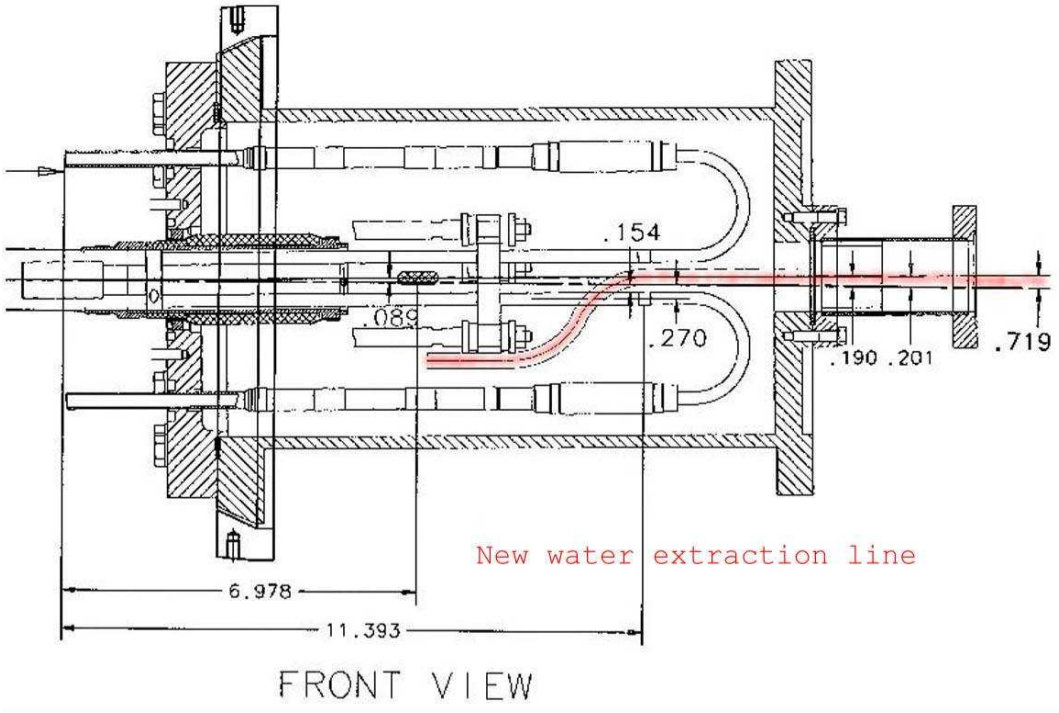




- On Horn1 upstream, Horn 2 upstream and downstream
  - 12 or 36 mm thick in longitudinal direction
- Also used Horn 1 Neck

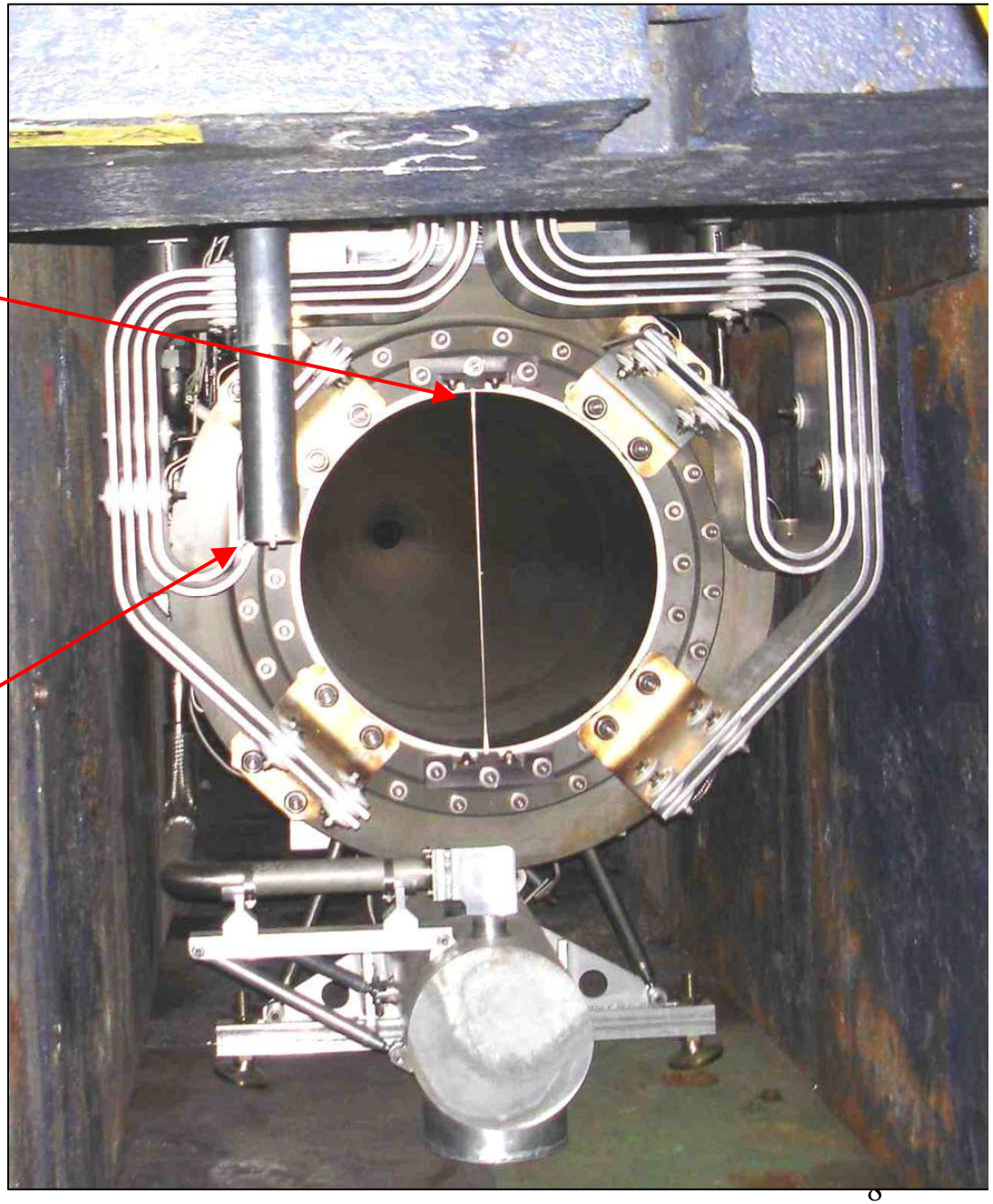
NuMI Budal Monitor

- Electrically isolated target
- Proton beam kicks off electrons and other charge particles from target segments
- Signal is read out
  - Proportional to beam intensity
  - Position dependent signal
- We need this on the new targets



Horn BLMs

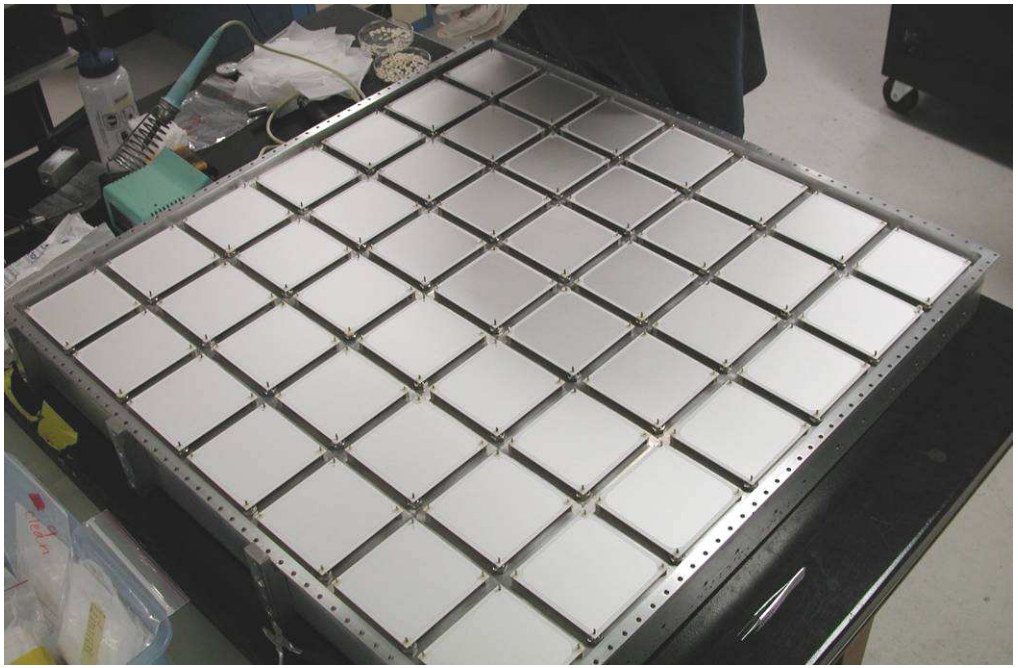
- Cross-hairs intercept primary proton beam
  - Target must be out
  - Beam also scatters on Horn 1 neck
- Two ion chambers measures particle spray
  - One downstream of each horn
  - Signals were not always measureable from background
- This system is needed and needs some improvement



NuMI Hadron Monitor

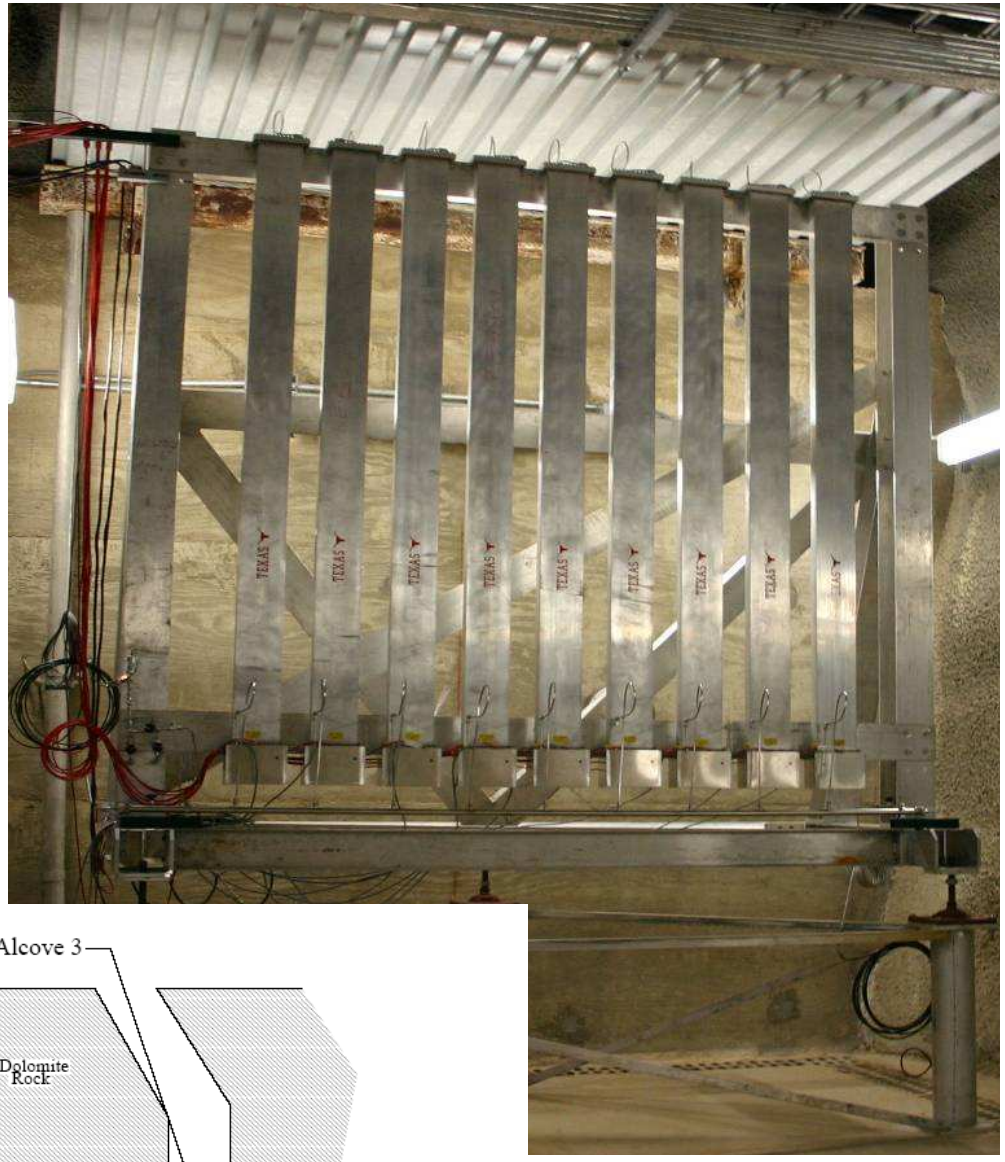
- Sits at end of decay pipe
- 7x7 pixels
- 1m x 1m
- Helium ionization chambers
  - 1 mm gap
  - Continuous flow
- High-radiation area
  - 10s of GRad

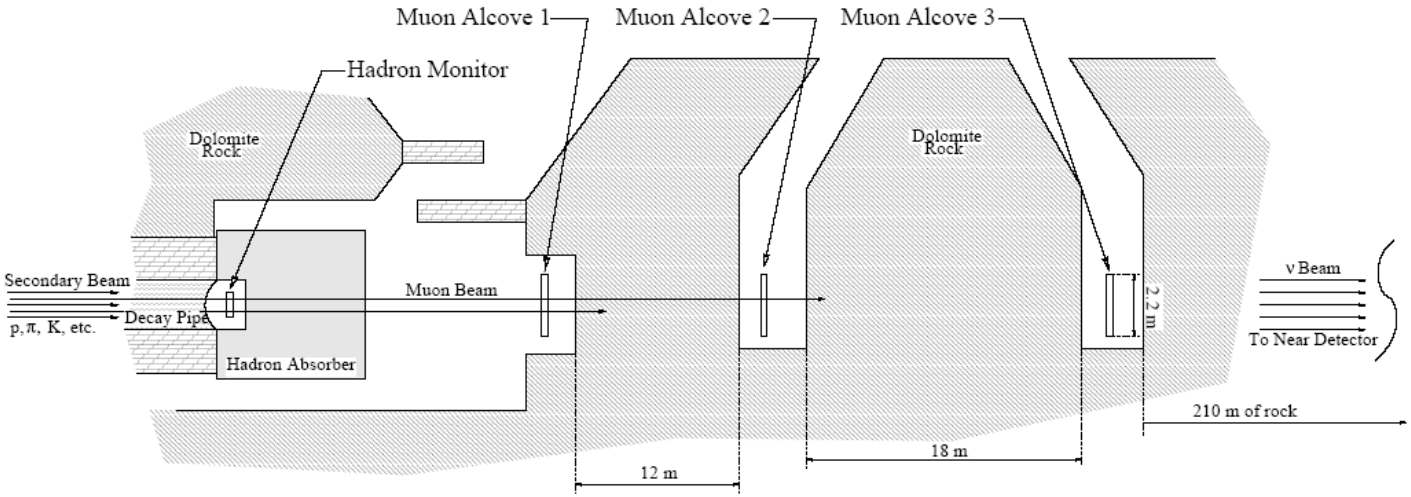
- We need this, but with improvements



NuMI Muon Monitors

- Located in alcoves after beam dump
- 9x9 (2m x 2m) ionization chamber arrays
  - 3mm gap version of HadMon
- Plagued by gas purity and electronics problems
- Sees hadron contamination form dump
  - Cause by cracks
  - TILT FROM PARALLEL!
- Usefulness was never fully demonstrated
  - Probably the regime of the LBNE ND group
  - Except possibly a target decay monitor

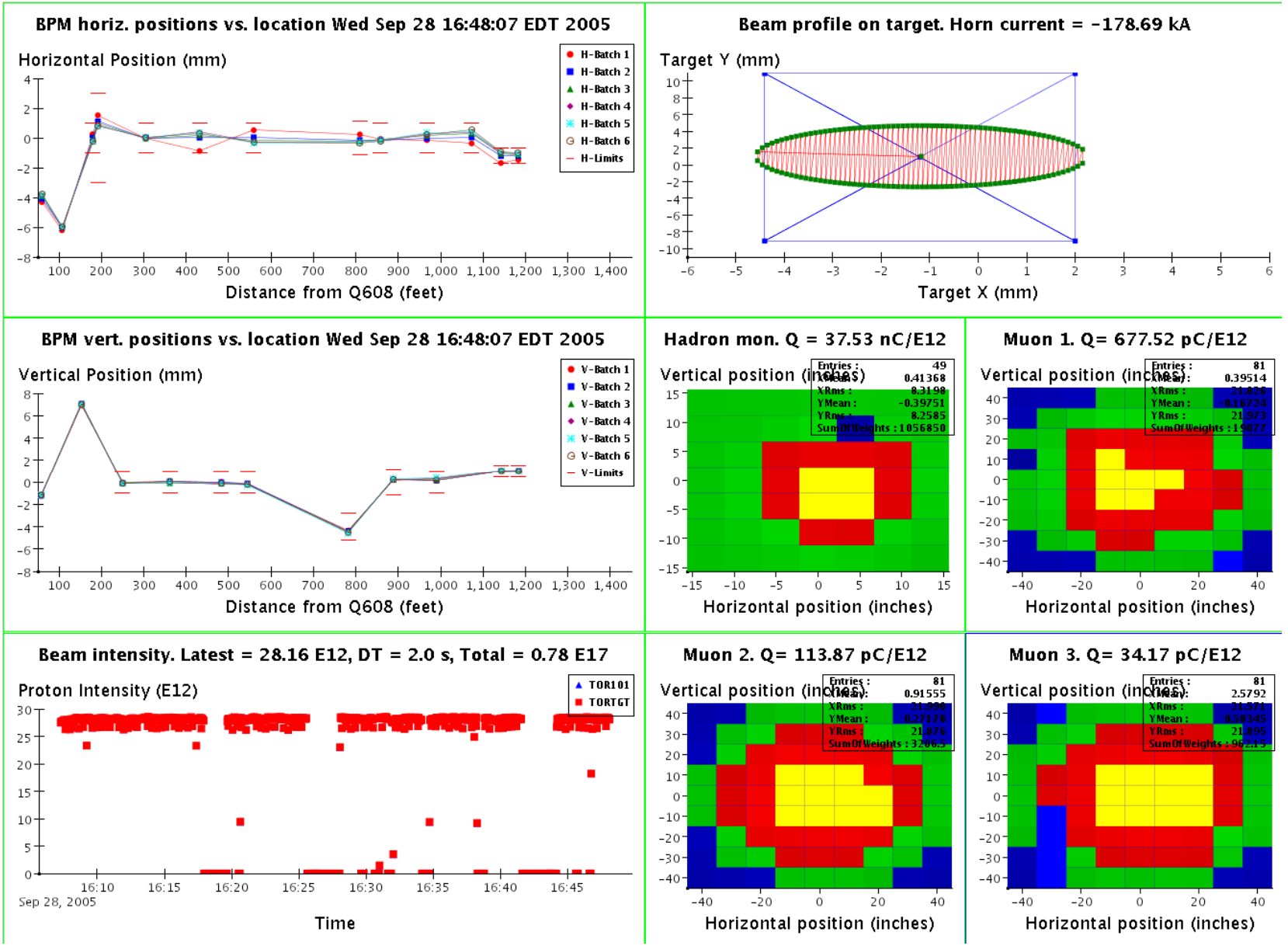




NuMI Software

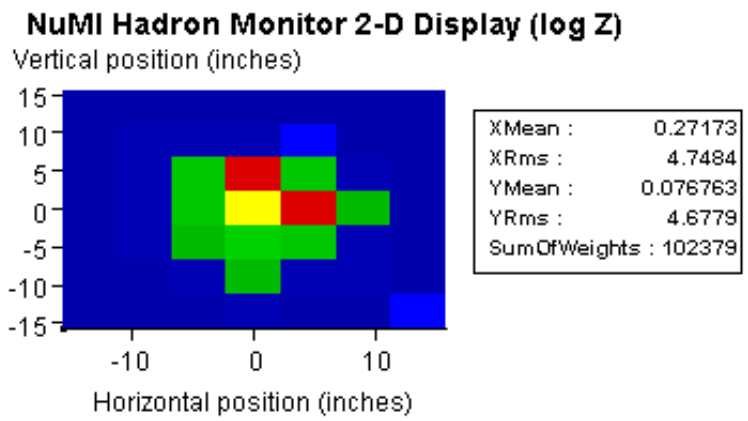
- Raw data was read into ACNET and MINOS data stream
  - Available for later analysis, however:
    - ACNET dataloggers not ideal for correlating different pieces of equipment
    - MINOS datastream only accessible to experts
- Online analysis was performed with JAS
  - Last-minute contribution from BNL
  - There had not been enough work planned on software
  - Many correlations between different pieces of multi-pixel equipment was needed
  - Decent for monitoring, not for analysis
- Software was a kludge and has not improved much since
  - Hinders us from performing frequent/detailed studies

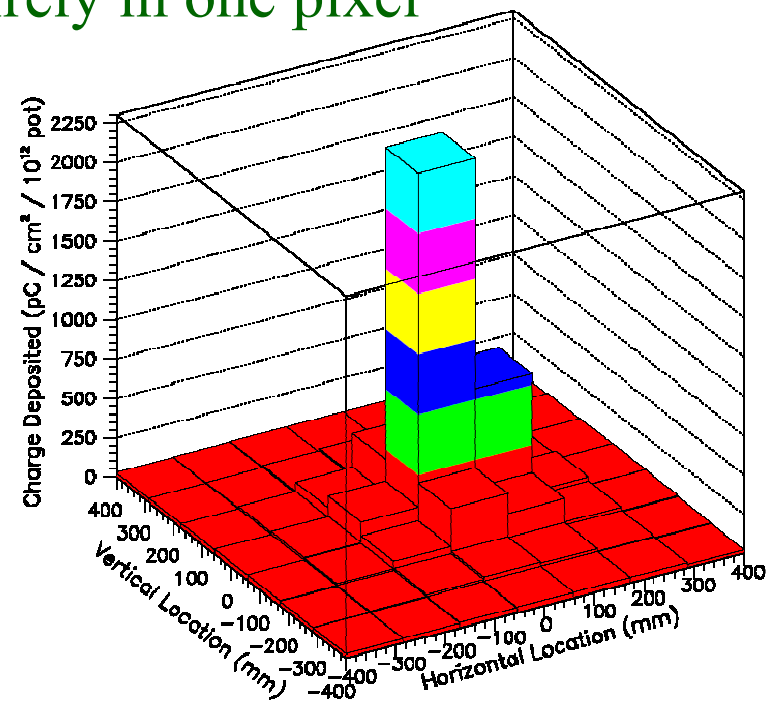
JAS Display

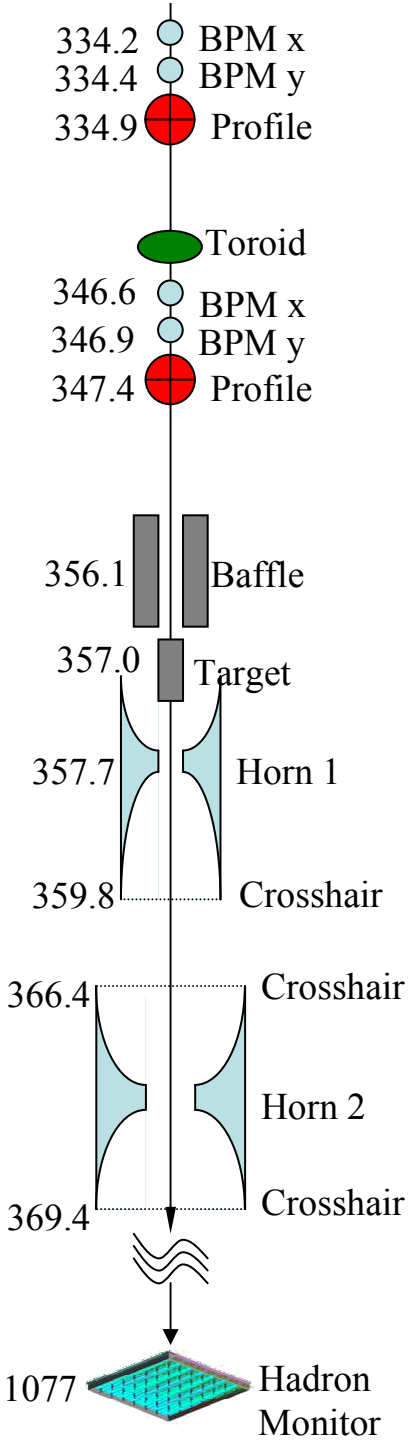

BPM horiz. positions vs. location Wed Sep 28 16:48:07 EDT 2005
Horizontal Position (mm)
H-Batch 1
H-Batch 2
H-Batch 3
H-Batch 4
H-Batch 5
H-Batch 6
H-Limits
Distance from Q608 (feet)
Beam profile on target. Horn current = -178.69 kA
Target Y (mm)
Target X (mm)
BPM vert. positions vs. location Wed Sep 28 16:48:07 EDT 2005
Vertical Position (mm)
V-Batch 1
V-Batch 2
V-Batch 3
V-Batch 4
V-Batch 5
V-Batch 6
V-Limits
Distance from Q608 (feet)
Hadron mon. Q = 37.53 nC/E12
Vertical position (inches)
Entries : 49
XMean : 0.41368
XRms : 8.3198
YMean : -0.39751
YRms : 8.2585
SumOfWeights : 1056850
Horizontal position (inches)
Muon 1. Q= 677.52 pC/E12
Vertical position (inches)
Entries : 81
XMean : 0.39514
XRms : 21.835
YMean : -0.16724
YRms : 21.973
SumOfWeights : 19077
Horizontal position (inches)
Beam intensity. Latest = 28.16 E12, DT = 2.0 s, Total = 0.78 E17
Proton Intensity (E12)
TOR101
TORTGT
Sep 28, 2005
Time
Muon 2. Q= 113.87 pC/E12
Vertical position (inches)
Entries : 81
XMean : 0.91555
XRms : 21.998
YMean : 0.27178
YRms : 21.876
SumOfWeights : 3206.5
Horizontal position (inches)
Muon 3. Q= 34.17 pC/E12
Vertical position (inches)
Entries : 81
XMean : 2.5792
XRms : 21.571
YMean : 0.53345
YRms : 21.895
SumOfWeights : 962.15
Horizontal position (inches)

NuMI Commissioning

- First "Target Hall" beam task was to shoot the beam down the primary beamline and through chase, with no target
  - Demonstrate that we can see spot at Hadron Monitor
  - Pointing of the beam
  - Worked, but beam was entirely in one pixel





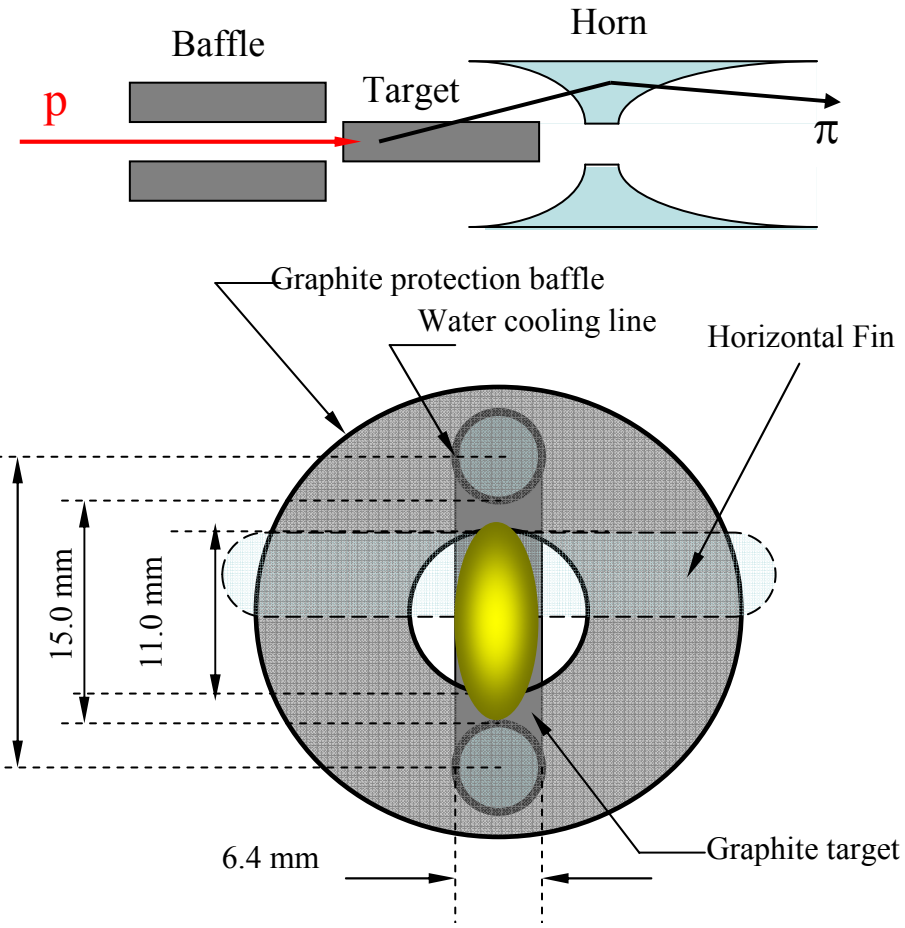


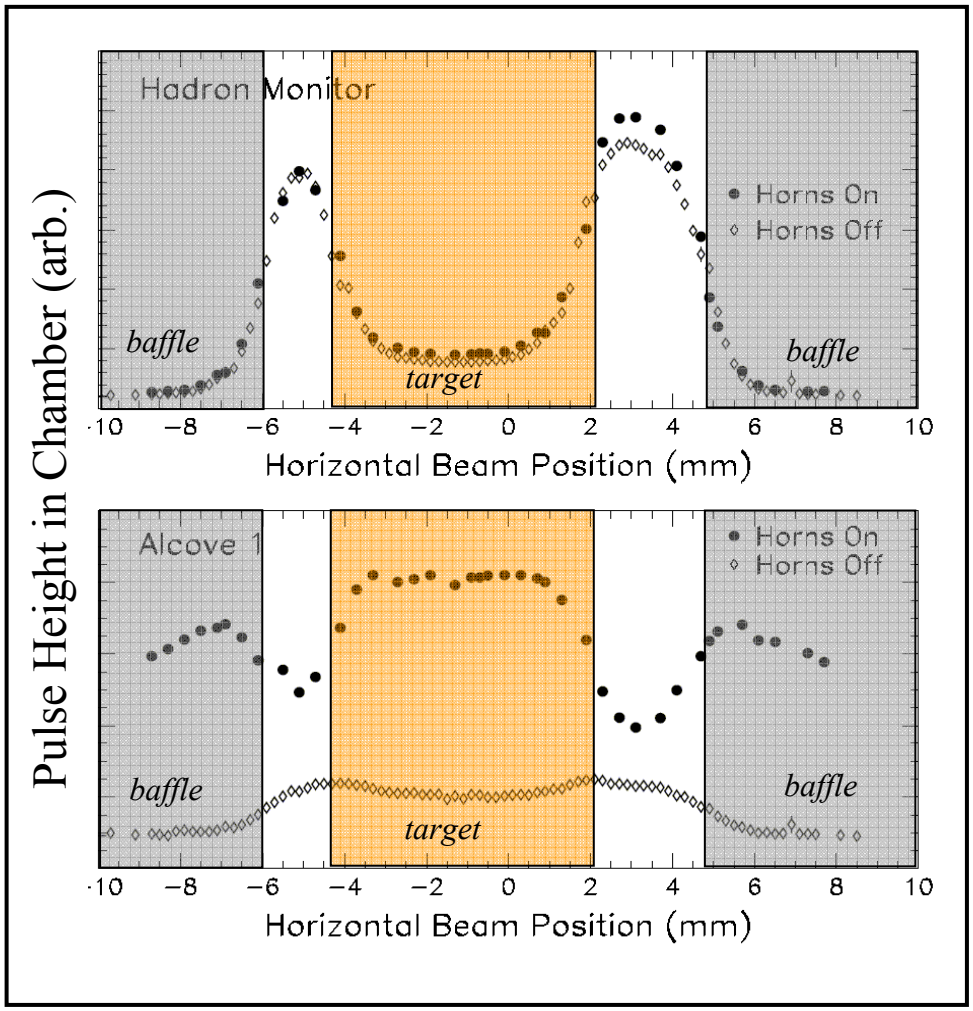
NuMI Beam-Based Alignment

- What would we like to align?
  - Target & Baffle
    - Meson production varies with amount of material traversed
    - Position of production important for other optics
  - Horns
    - Focusing depends on positioning and angle
- Procedure
  - Scan proton beam across known features of beamline components
    - Target & Baffle material
    - Horn neck and cross-hairs
  - Use instrumentation to correlate measured proton beam position with component features
    - Target budal Monitors
    - Loss Monitors in the target hall
    - Hadron and Muon Monitors

Target Alignment

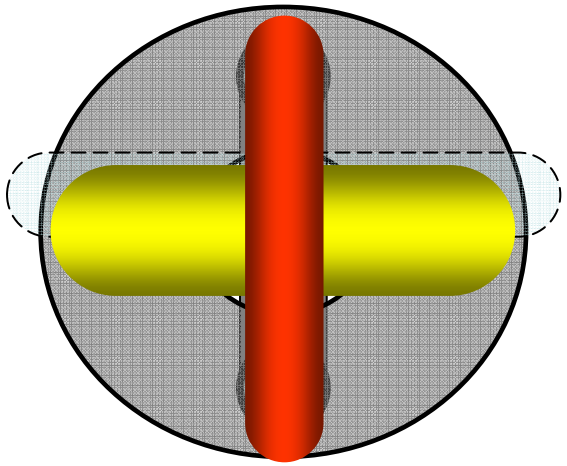
- Proton beam scanned horizontally across target and protection baffle
  - Also used to locate horns
- Hadron Monitor and the Muon Monitors used to find the edges
  - Measured small (~1.2 mm) offset of target relative to primary beam instrumentation.

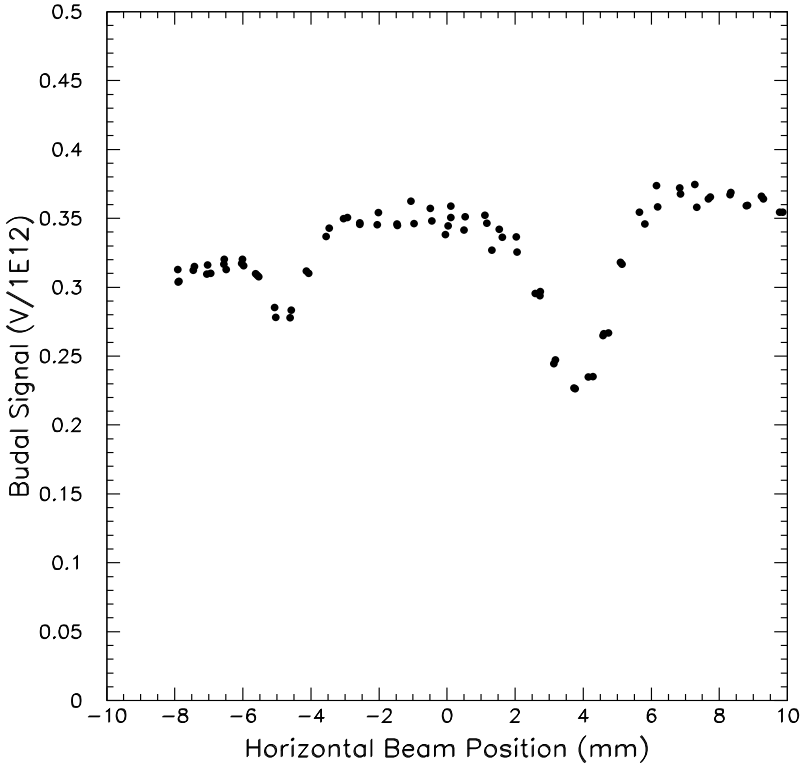


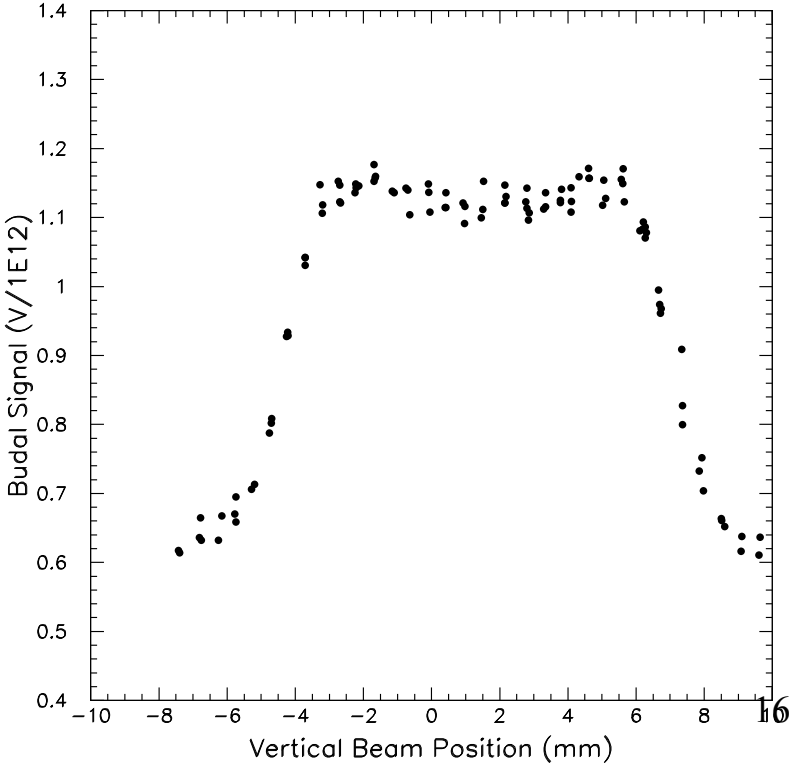


Budal Monitor Performance

- Horizontal Budal measurement consistent with Hadron Monitor
- Vertical measurement corresponds to baffle aperture – not horizontal fin
  - ➢ Several possibilities to affect Budal signal

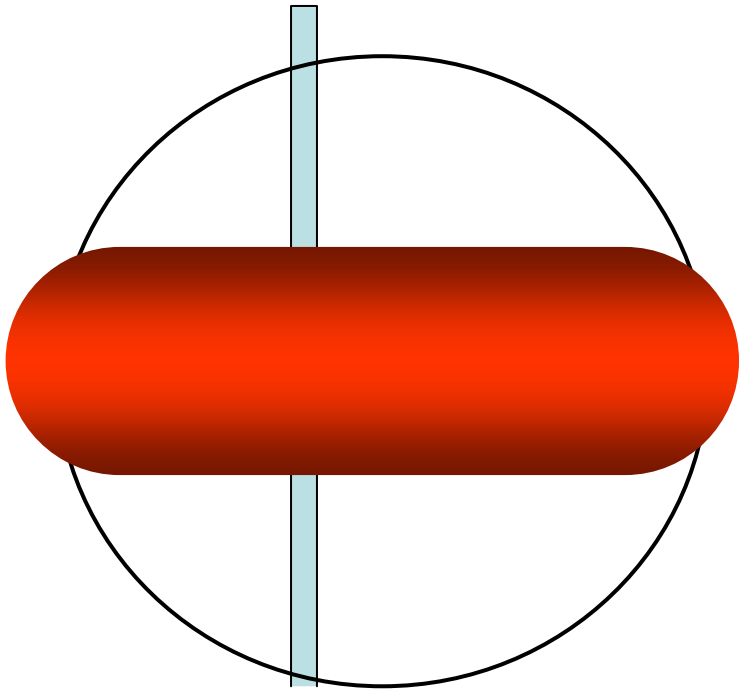


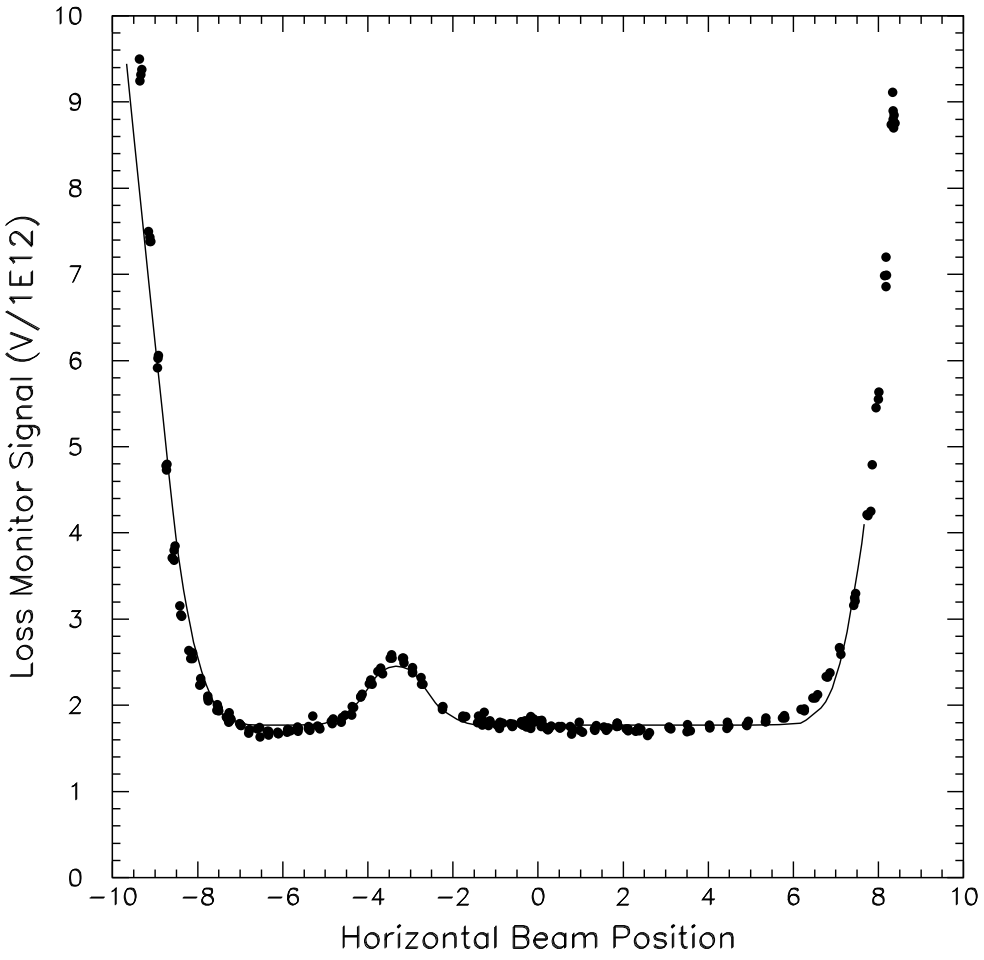




Horn 1 Horizontal Position

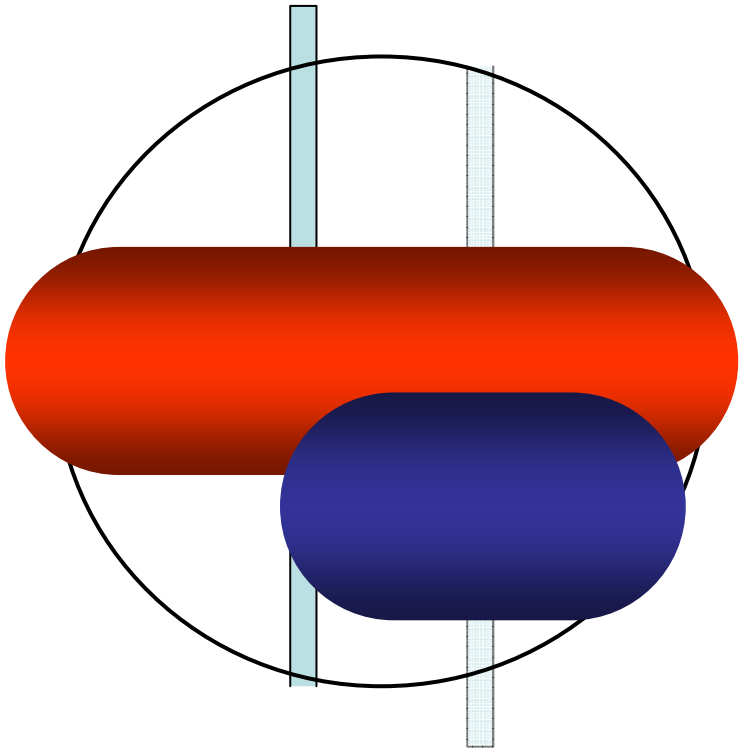
- Horn 1 LM sees clean signal due to cross-hair
- Neck also cleanly resolved

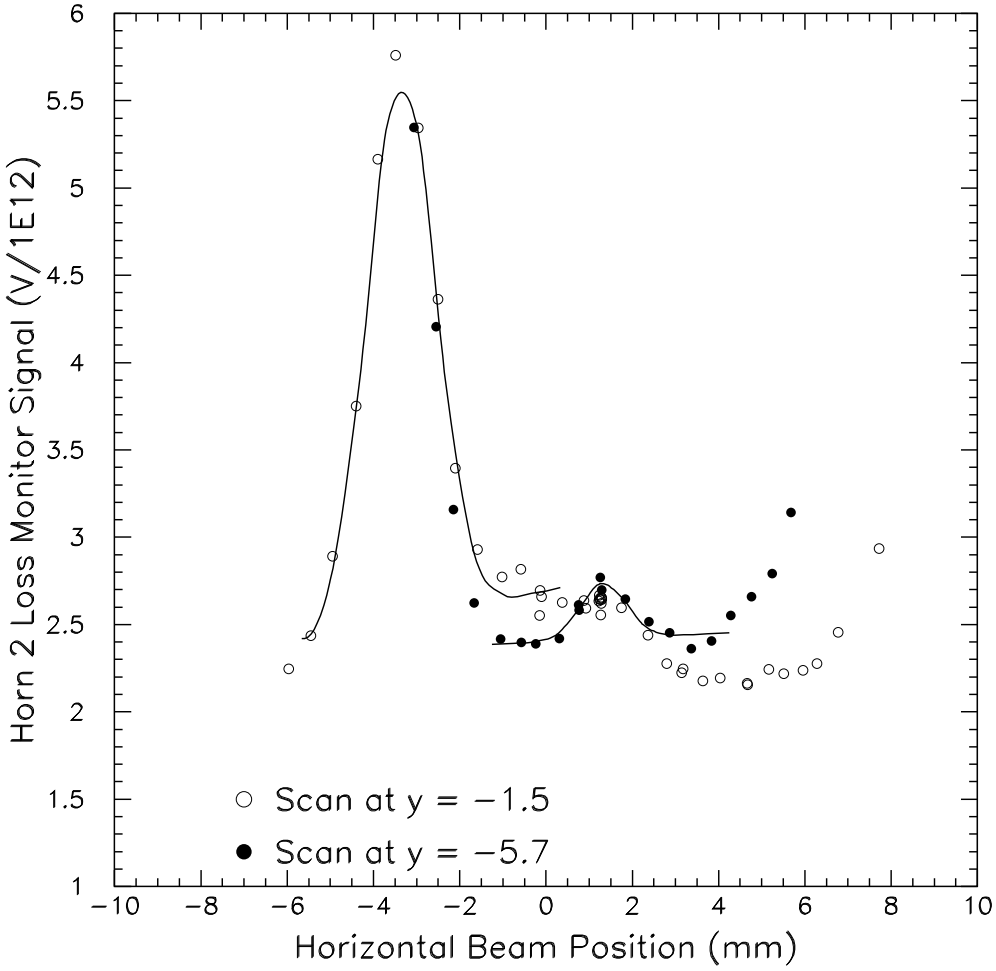




Horn 2 Horizontal Positions

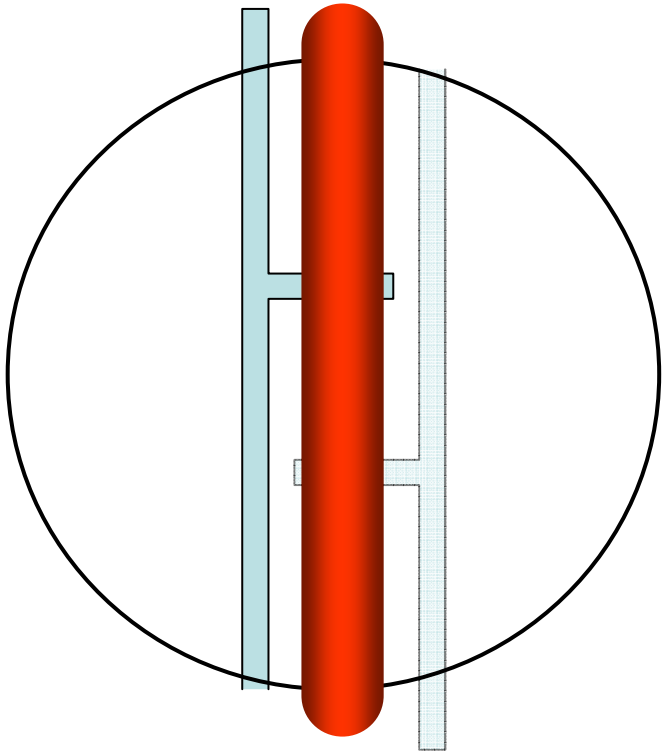
- Downstream cross-hair not resolvable in first scan
  - ➢ Upstream nub interferes
- Displace scan resolves the nub

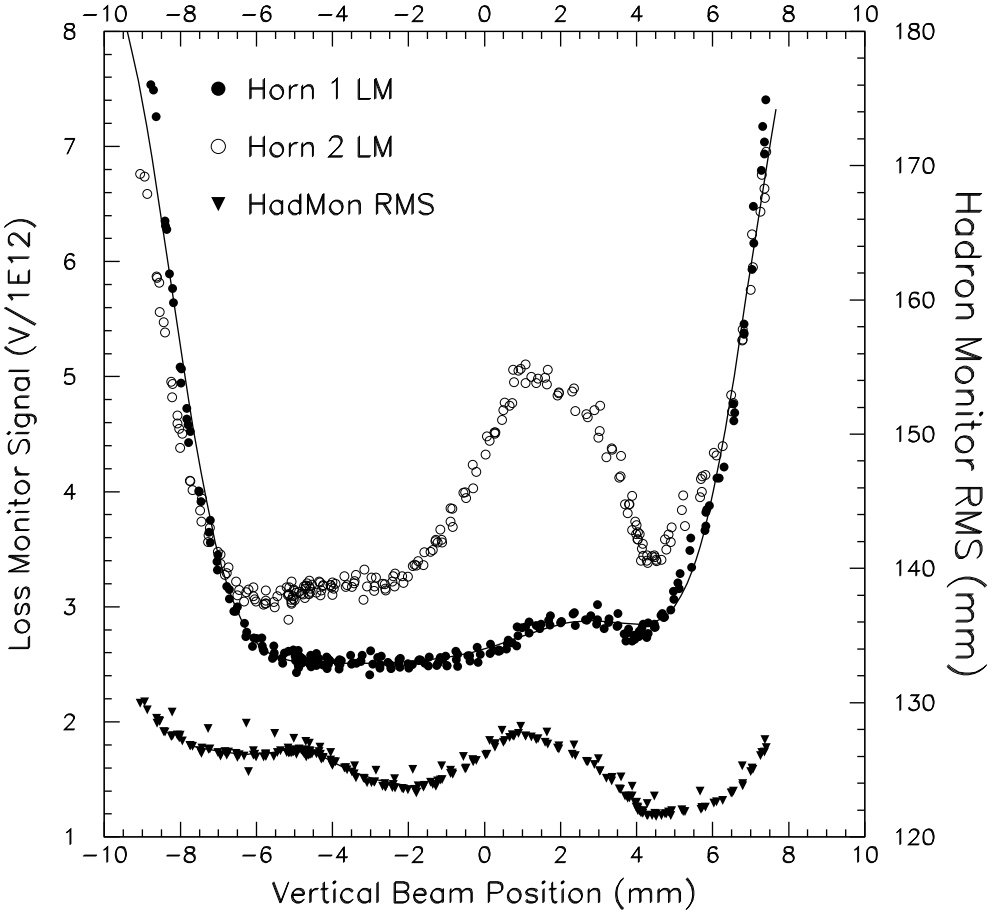




Horn Vertical Positions

- Vertical scan looks for nubs
- Hadron Monitor RMS used for finding DS nub
  - ➢ LM could not extract signal
  - ➢ Not the beast measurement





Alignment Results

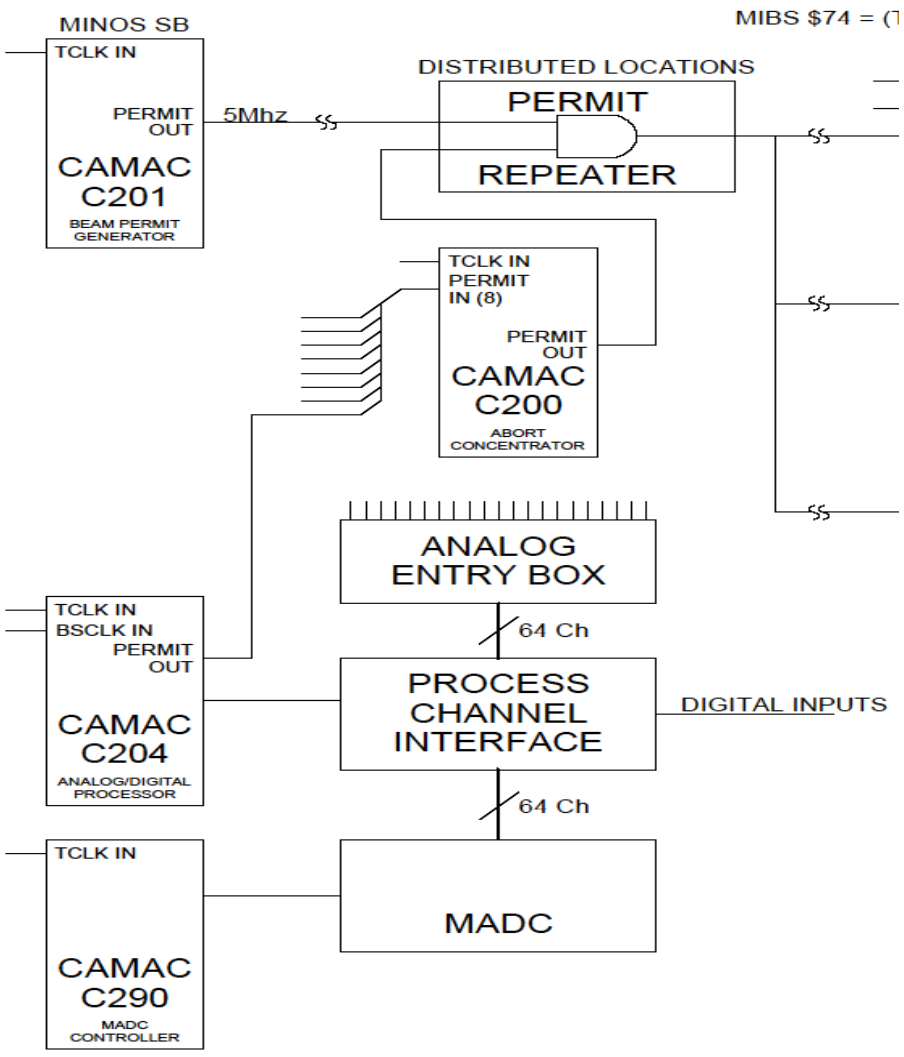
- Estimate effects on beam as a result of offsets measured
  - F/N ration is figure of merit
  - Use parameterization based on simulations
  - These are upper bounds as the worst effects are in higher-(ν)energy bins
  - Error budget is ~ 2%
- If beam were to be initially directed at (0,0) the budget would be exceeded
- However, beam is pointed using the alignment measurements
  - Target center horizontally
  - Baffle center vertically
- Larger offsets to optical survey were later found to be associated with settling and thermal variation

Device	Dir.	Offset	Effect	Angle	Effect
Baffle	Horz	-1.2 mm	2.5%	-0.1 mrad	< 0.1%
Baffle	Vert	+1.1	2.2	-0.7	< 0.1
Target	Horz	-1.4	2.5	-0.1	< 0.1
Target	Vert	+0.1	< 0.1	-0.7	0.3
Horn 1	Horz	-1.2	1.1	-0.2	0.3
Horn 1	Vert	+0.8	1.4	+0.3	0.4
Horn 2	Horz	-1.8	1.2	-0.2	< 0.1
Horn 2	Vert	+0.1	< 0.1	-0.4	< 0.1

Device	Dir.	Offset	Effect	Angle	Effect
Baffle	Horz	0.0 mm	< 0.1%	-0.1 mrad	< 0.1%
Baffle	Vert	+0.1	< 0.1	-0.7	< 0.1
Target	Horz	-0.2	0.4	-0.1	< 0.1
Target	Vert	-0.9	< 0.1	-0.7	0.3
Horn 1	Horz	-0.0	< 0.1	-0.2	0.3
Horn 1	Vert	-0.2	< 0.1	+0.3	0.4
Horn 2	Horz	-0.6	0.2	-0.2	< 0.1
Horn 2	Vert	-0.9	0.4	-0.4	< 0.1

High-Intensity: Beam Permit System

- Inhibits beam on a rapid basis
- > 200 inputs
- Checks that radiation levels have not been exceeded
  - Prevents beam from being accelerated
- Beamline components – e.g. magnet ramps
  - Can prevent acceleration, but also extraction
- Beam quality in Main Injector
  - Position, abort gap
- This system may have to take more inputs for LBNE
  - E.g.: from Hadron Monitor



Long-term Running

- Hadron and Muon Monitors can see variations in target and horn
  - However, the detectors drift due to gas and electronics issues
  - We will need some subset of their functionality for LBNE

- Specific need: Target Decay

NuMI target experience

(ZXF-5Q amorphous graphite)

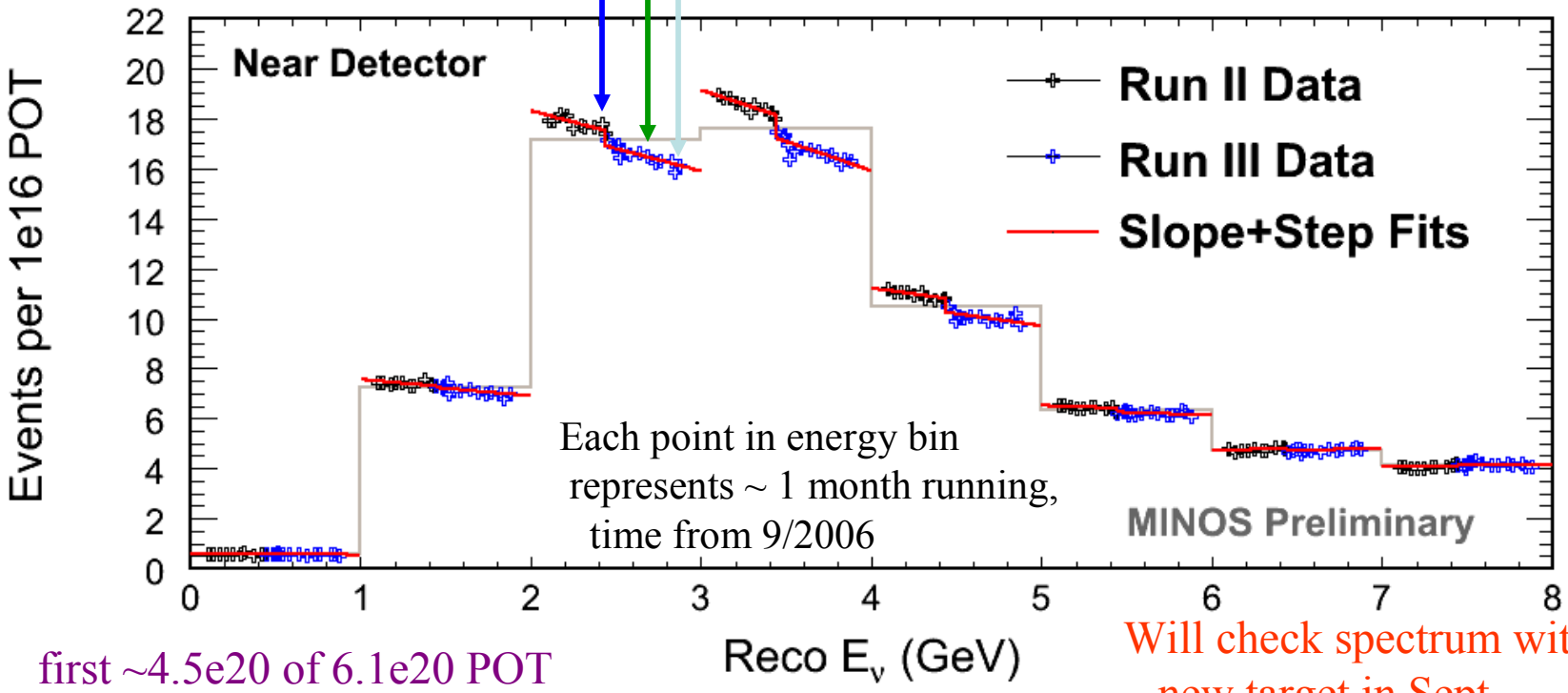
f/ Jim H.

Gradual decrease in neutrino rate attributed to target radiation damage

Decrease as expected when decay pipe changed from vacuum to helium fill

No change when horn 1 was replaced

No change when horn 2 was replaced

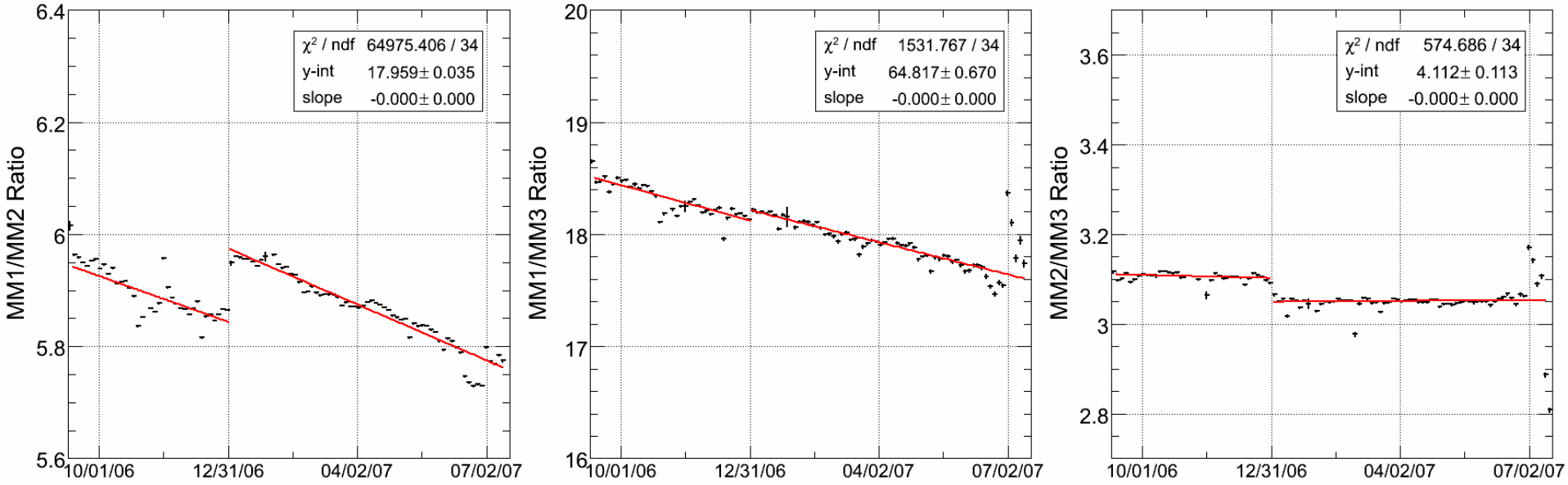


first ~4.5e20 of 6.1e20 POT
on NT-02 shown on this plot

Will check spectrum with
new target in Sept.

Target Decay in Muon Monitors

- Ratios of muon monitors seen to vary with target decay
- A simplified muon monitor behind the dump and in an alcove could provide an effective target decay monitor
- We need to be able to monitor target degradation without waiting for data to be processed form the neutrino detector



f/ Laura Loiacono

Needs for External Instrumentation

- BPMs / profile monitors
  - ➢ Precise positions and widths at low-intensity
  - ➢ Able to look within the train
    - NuMI has 6 batches, would be nice to look smaller
  - ➢ Optical survey data needed at time of commissioning
- Everything should be cataloged into ACNET and the datastreams, but we should also have a unified way of looking at the data

Needs for Target/Baffle/Horn Features

- We need some high contrast features in the new target and baffle to align with
  - Baffle edges are good, but we would like upstream and downstream features to get angles
- Will target edges be enough?
  - It is larger now, and potentially entirely obscured by the baffle
  - Need some way to ascertain angle
- We need cross-hairs and/or necks to be resolvable on horns
  - Should rethink whether there is some way to have a less cluttered aperture
  - Will cross-hairs survive high-intensity beam?

Needs for Target Hall Instrumentation

- Thermocouples: wherever possible, particularly baffle
- Budal monitor: Yes, working at startup
  - Other target monitoring? Zero-degree?
- Loss Monitors: Yes, but need to be positioned to resolve features
  - Also, would be nice to do some continuous monitoring
- Hadron Monitor: Yes
  - Need higher resolution in middle
  - Larger coverage generally?
  - Needs to be made replaceable, and more reliable
- Muon Monitor: Maybe
  - Detailed muon monitor for physics better left to ND group
  - We need a simplified, reliable, target decay monitor

Needs for Software

- Need to make sure that ACNET and/or experimental datastream can separate individual events
  - Timestamps need to be accurate
    - Better yet, have a spill number associated with each datum
- Then, need to be able to extract and correlate necessary data
  - Reconstructed proton beam position and width at features
  - Compare different sources of measurement at the same time
  - Be able to fit complicated, arbitrary functions
- Also, automated scanning would save time and cut down on operator error
- Another monitoring application is needed

  - Can be tested with NuMI beam

Need for Simulation

- The deviation of F/N with component displacement
  - Vary positions and angles to get parameterization
  - Important input to get alignment tolerances
  - Probably need experimental limit on F/N error
- Need simulations of alignment/commissioning and response in instrumentation
  - Need to get specifications for instrumentation of:
    - Signal strength (particle fluxes)
    - Radiation Damage / Activation
    - Heating

Prototyping/Experimenting

- Several devices need some research and should be prototyped and/or tested with beam in advance
  - Cross-hair – BLM system needs to be tested for noise / calibrated
  - Hadron Monitor is a difficult device to design
    - Probably needs beam tests and a lot of work
  - Target decay (Muon Monitors) need some testing

- Some of the above could be tested in the NuMI beam
- Some would be better suited to test beams

Summary

- NuMI gives us a solid example for target hall instrumentation
  - Used for commissioning, alignment, beam permit, and long-term monitoring
- Generally, we still need more and better
  - Redundant devices
  - Greater reliability – lower barrier to usage
- All of the instrumentation should be, at minimum, repeated
  - Muon monitor may be simplified to a target decay monitor
- Target/baffle/horn must retain features on which to align
- Software, and integration generally, is needed to make sure all the devices fulfill their purposes

LBNE Target Hall Instrumentation

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January 27, 2010